Environmental performance of wild-caught North Sea whitefish

A comparison with aquaculture and animal husbandry using LCA

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Het LEI ontwikkelt voor overheden en bedrijfsleven sociaal economische kennis op het gebied van voedsel, landbouw, groene en blauwe ruimten. Met onafhankelijk onderzoek biedt het zijn afnemers houvast voor maatschappelijk en strategisch verantwoorde beleidskeuzes.

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Dierlijke Productie Systemen (DPS) is een leerstoel binnen het Departement Dierwetenschappen en houdt zich bezig met het analyseren van de complexiteit van duurzaamheidsvraagstukken in de veehouderij, met als doel een bijdrage te leveren aan een duurzame toekomst. Het onderzoek richt zich op systemen in zowel ontwikkelde als ontwikkelingslanden, op bedrijfs-, keten- en regioniveau. Speciale aandacht gaat uit naar het ontwikkelen van methoden voor het exploreren van de interactie tussen milieubelasting, dierenwelzijn en economie. Prof. Imke J.M. de Boer, hoofd van DPS, adviseert TSC (The Sustainability Consortium) aangaande wetenschappelijke vraagstukken rondom het meten van duurzaamheid in de keten van producten.

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Contents

Preface

Dutch fisheries are under pressure. They face heavy competition from imported products from the aquaculture sector. In the public opinion, fisheries are held responsible for loss of biodiversity and damage to the environment. The challenge is to identify the qualities of North Sea fish and to improve the market position.

In this study, we researched the environmental impact of plaice and cod. We used the LCA methodology to get a solid scientific insight into the environmental performance and to allow for a comparison with imported fish from aquaculture and meat.

It is remarkable that while so much is said about the environmental impact of fisheries, a study like this has not been done before. The LCA shows that the environmental impact of fisheries is comparable with that of aquaculture. It is also clear that a great deal of effort is spent on new fishing techniques and fuel-saving technologies. These may lead to significant reductions in the environmental impact.

A single study will not change the market position of Dutch fisheries, but it is a starting point. We recognise that some data are still lacking and should be included to improve comparisons. The North Sea fisheries sector now has a better idea of where it stands in terms of its environmental performance and where it should be heading. The most important quality is the ability to innovate and improve the environmental performance. For politicians and the public this is not always clear, and therein lies a major challenge for the sector.

We would like to thank Auke van de Kerk (Jaczon), Christien Absil (Stichting De Noordzee), Johan van Nieuwenhuijzen (United Fish Auctions) and Gerard den Heijer (W.G. Den Heijer) for their involvement in this research.

This research was initiated by Auke van der Kerk (Jaczon) and funded by the *Visserij Innovatie Platform*. This research is a joint collaboration between LEI and ASG, both parts of Wageningen UR.

A management summary (in Dutch) of this report is published separately and is titled *Duurzame Noordzeevisserij; Milieuprestaties Noordzeevis, kweekvis en vlees vergeleken.* LEI-publication 11-154.

Prof Dr R.B.M. Huirne
Managing Director LEI

Summary

S.1 Key findings

The environmental impact of North Sea plaice and cod lies within the same range as that of salmon, tilapia and pangasius from aquaculture, the most important import fish. Although catch of plaice and cod requires more energy than meat production, the global warming potential (GWP) is comparable. Foreseen technological innovations make it possible to reduce environmental impacts of plaice and cod significantly.

Current life cycle analysis (LCA) results do not show a significant difference in energy use or global warming potential per kg fillet of plaice, cod, salmon, tilapia and pangasius. Though there are some differences in the mean values, the variance in the data is too great.

Current LCA results do not show a significant difference in acidification potential per kg filet of cod and plaice or salmon, tilapia or pangasius. Eutrophication potential of plaice and cod is lower than eutrophication potential of salmon, tilapia and pangasius. (See Paragraph 2.2)

Energy use for plaice and cod is higher than energy use for beef, pork and chicken. GWP of plaice and cod is comparable to GWP of pork and chicken and lower than GWP of beef. This is explained by the non-CO_2 greenhouse gas emissions from animals and manure. (See Chapter 3)

S.2 Complementary findings

In general, both wild caught and aquaculture can improve their environmental performance, but the effects of improvements in aquaculture do not seem to be as straightforward as in fisheries. (See Chapter 4)

All technologies that reduce fuel use have a direct positive impact on the LCA. These directly reduce energy consumption and GWP. Other changes, such as a shift to biofuels, all come with pros and cons.

Land use is only important in aquaculture. This land is used to cultivate feed ingredients. Fisheries often have an impact on the ecosystems in the sea. Biodiversity is influenced by disrupting the seabed and by the exploitation of fish resources. Given the lack of validated data, it is impossible to quantify these impacts and weigh them against other impact categories using LCA.

S.3 Methodology

Since 2008, market price for various wild-caught North Sea whitefish has shown a sharp decrease. Next to this wild-caught whitefish from the North Sea, caught and landed by Dutch fishers, suffers from a bad image. A better market positioning of North Sea fish is required for securing a healthy sector in the future. Sustainability can be an important notion here, emphasising the qualities of North Sea fish in terms of people, planet and profit.

The objective of this research is to examine the qualities of wild-caught North Sea whitefish in comparison to imported aquaculture fish and meat. In particular, we aim to research the environmental performance.

In this research, we take the following steps.

1. We perform a life cycle assessment of plaice and cod, in comparison with the imported aquaculture. This step can be considered the core of the research
2. We compare the results with results from life cycle assessment of meat (pork, chicken, beef).
3. We describe how expected improvements in both fishing and aquaculture will affect the outcome of life cycle assessment.

Data on the environmental impact of sole was not available; we therefore focussed on plaice and cod.

Samenvatting

Milieuprestaties van wild gevangen witvis uit de Noordzee; een vergelijking met vis uit aquacultuur en vlees met behulp van LCA

S.1 Belangrijkste uitkomsten

De milieuprestaties van schol en kabeljauw uit de Noordzee zijn vergelijkbaar met die van geïmporteerde, gekweekte zalm, tilapia en pangasius. Hoewel de vangst van schol en kabeljauw meer energie vraagt dan de productie van vlees, is de bijdrage aan de productie van broeikasgas (dat klimaatverandering veroorzaakt, Global Warming Potential, GWP) vergelijkbaar. Naar verwachting worden de milieuprestaties van schol en kabeljauw sterk verbeterd door toepassing van technologische innovaties.

De resultaten van de levenscyclusanalyse (LCA) laten zien dat er geen significante verschillen zijn tussen het energieverbruik en het GWP van schol en kabeljauw enerzijds en zalm, tilapia en pangasius anderzijds. Er zijn weliswaar verschillen in de gemiddelde waarde, maar de variatie is dermate groot dat er geen sprake is van significante verschillen.

Het energieverbruik voor de vangst van schol en kabeljauw is groter dan het energieverbruik voor de productie van vlees. De bijdrage aan klimaatverandering van schol en kabeljauw is vergelijkbaar met de bijdrage van varkensvlees en kip, en kleiner dan de bijdrage van rundvlees. Dit komt doordat de productie van vlees gepaard gaat met emissies van andere broeikasgassen dan CO_2.

S.2 Overige uitkomsten

De verwachte technologische verbeteringen in de visserij en aquacultuur bieden mogelijkheden om de milieuprestaties te verbeteren, maar de verbetering in aquacultuur zijn minder rechtaan dan bij visserij.

Alle technieken die leiden tot brandstofbesparing hebben een positief effect op de LCA. Zij hebben een direct effect op het energieverbruik en het GWP.

Andere veranderingen, zoals het gebruik van biobrandstoffen, hebben voor- en nadelen.

Landgebruik is alleen belangrijk bij aquacultuur. Hier is land nodig voor de productie van voedsel. Visserij heeft vaak een effect op de ecosystemen in de zee. De biodiversiteit wordt aangetast door beroering van de zeebodem en de exploitatie van visvoorraden. Het is met de huidige beschikbare informatie onmogelijk om deze verschillende impacts tegen elkaar af te wegen in een LCA.

S.3 Methode

Sinds 2008 is de prijs voor verschillende soorten wild gevangen witvis uit de Noordzee sterk gedaald. Daarnaast heeft de Noordzee witvis visserij in het algemeen een slecht imago. Een betere positionering in de markt is noodzakelijk voor een gezonde toekomst van de sector. Duurzaamheid kan een belangrijk aanknopingspunt zijn om de kwaliteit van Noordzeevis te benadrukken.

Dit onderzoek heeft tot doel om de kwaliteiten van wild gevangen witvis uit de Noordzee in kaart te brengen en te vergelijken met de kwaliteiten van geïmporteerde, gekweekte vis en van vlees. We richten ons daarbij in het bijzonder op de milieuprestaties.

In dit onderzoek doorlopen we de volgende stappen:

1. We voeren een LCA uit om de milieuprestaties van schol en kabeljauw in kaart te brengen en te vergelijken met die van zalm, tilapia en pangasius. Deze analyse is te beschouwen als de kern van het onderzoek.
2. We vergelijken de resultaten van de LCA met de resultaten van LCA-onderzoek naar rundvlees, varkensvlees en kip.
3. We beschrijven welke impact verwachte verbeteringen in de visserij en aquacultuur zullen hebben op de LCA.

Omdat er geen data voor tong beschikbaar waren, hebben we ons voor Noordzeevis gericht op schol en kabeljauw.

1 Introduction

1.1 Background

Since 2008, the market price for various wild-caught North Sea whitefish (mainly plaice and cod) has shown a sharp decrease, in all channels of distribution. Various relatively cheap whitefish products are imported in large quantities in Europe and compete with wild-caught, freshly landed North Sea whitefish. In France and Spain, this has already led to serious problems for the domestic fishing sector, and if current developments continue, the Dutch fishing sector will also be confronted with serious problems.

Wild-caught whitefish from the North Sea, caught and landed by Dutch fishers, also suffers from a bad image. Consequently, there is a problem in marketing the product, both within the Netherlands and abroad. A single campaign to promote wild-caught North Sea whitefish only delivers short-term results and does not bring the desired long-term improvements in the product's positioning. In combination with declining prices and increased competition, this poses a serious threat to the Dutch fishing sector. Measures to combat this are called for.

We believe that better market positioning of North Sea fish is required in order to secure a healthy sector in the future. Sustainability can be an important topic here, emphasising the qualities of North Sea fish in terms of people, planet and profit.

The Dutch cutter fishers recognise the importance of sustainability, and they work hard on innovations for improving the sustainability performance of the sector's products and production methods. Rapid developments are taking place in fishing techniques, such as the development of pulse trawl fishing. To maintain its economic viability and societal licence to produce, the sector invests in technologies that save fuel and reduce the impact on the environment. The sector is also engaged in the improvement of the management of the North Sea and its natural resources, in collaboration with government and social actors.

Society places great importance on the sustainable production of fish, yet there is no precise definition of sustainably produced fish. Neither is there a methodology for a scientifically valid comparison of the sustainability performance of various fish products, nor for the evaluation of new technologies. To improve the positioning of wild-caught whitefish, it is necessary to have more and better information on the qualities of the North Sea species which are most important commercially in comparison with competing aquaculture species and meat.

1.2 Research goal

The objective of this study is to examine various aspects of the environmental impact of wild-caught North Sea whitefish in comparison to imported aquaculture fish and meat. In particular, we aim to research whether or not claims on the environmental impact can be supported by scientific data.

Given the lack of knowledge about environmental impact, a desk study was performed for some of the whitefish species which are most important economically. The desk study aimed to collect information on the performance of the North Sea species plaice and cod and to compare this with salmon, tilapia and pangasius from aquaculture. The focus was on energy use, global warming potential, acidification, eutrophication and land use. Subsequently, the environmental impact of beef, pork and chicken was investigated and compared with that of wild-caught North Sea whitefish.

It was then possible to determine what information is lacking and could be included in future follow-up studies of the environmental impact of wild-caught North Sea whitefish.

1.3 Methodology

In this study, we have taken the following steps:

1. Performing a life cycle assessment of plaice and cod, in comparison with the imported aquaculture. This step can be seen as the core of the research (more information below).
2. Comparing the results with results from life cycle assessment of meat (pork, chicken, beef).
3. Describing how expected improvements in both fishing and aquaculture will affect the outcome of life cycle assessment.

The core of this study is the life cycle assessment (LCA). An LCA is a holistic method for evaluating the environmental impact during the entire life cycle of a product. Two types of environmental impact are considered during the life cycle of a product: the use of resources such as land or fossil fuels, and the emission of pollutants such as ammonia or methane (Guinée *et al.*, 2002). The emission of pollutants contributes to categories of environmental impact such as climate change, the acidification and eutrophication of ecosystems, and human or terrestrial ecotoxicity. A carbon footprint is basically a single-issue LCA, focussing only on the emission of greenhouse gases through the life cycle of a product. In this report, we use the notion of global warming potential (GWP) instead of a carbon footprint.

1.4 Disposition of report

Chapter 2 presents the results of the comparison between wild-caught North Sea whitefish and imported aquaculture, using a life cycle assessment. Chapter 3 describes the results of the life cycle assessment of meat and compares these with the findings in Chapter 2. Chapter 4 describes how expected developments in the fishery and aquaculture sectors will affect the outcome of the life cycle assessment. Chapter 5 contains a discussion of the findings and conclusions, as well as recommendations for further research.

2 Environmental impact of wild-caught fishing in comparison to aquaculture

2.1 Introduction

The aim of this section is to compare the LCA results of different fish species, based on the literature. We found thirteen articles and two reviews in peer-reviewed scientific journals and scientific reports examining the environmental impact of individual fish products (see Table 2.1). These studies described the LCA results of products from fishery or aquaculture for one or more species and diverging production systems. As we were interested in comparing the environmental impact of wild-caught plaice and cod versus farmed salmon, tilapia and pangasius (data is collected on striped catfish, *Pangasiadom hypophthalmus*), we focused on these species only (numbers 1-13 in Table 2.1). We included the only LCA of a recirculation aquaculture system (RAS), which evaluated char, to demonstrate the strengths and weaknesses of RASs.

An LCA expresses the environmental impact of a defined system in relation to a functional unit, which is the main function of the system expressed in quantitative terms. The majority of LCA studies evaluate the production stages until the farm gate and leave out succeeding stages, such as processing, retail and household consumption. We recalculated the results of the different studies to cradle-to-farm-gate boundaries. The functional unit in our system, therefore, is one kg of fresh fillet accounting for the amount of live weight required to produce one kg of marketable product, excluding the processing and transport stages. Because the initiators of this research wanted to compare the product at the Dutch market, we have also described the environmental impact in relation to post-farm gate processing and transport to the Netherlands.

We have excluded the environmental impact in relation to infrastructure from our analysis. Infrastructure is often excluded from agricultural LCAs because the great deal of time it takes to include the infrastructure is not proportional to the relatively small environmental impact (Aubin *et al.*, 2006; Vásquez *et al.*, 2010). Some studies include the environmental impact of the use of refrigerants in their analyses because its production and use results in high emissions of greenhouse gases. The refrigerants in current use, however, have almost no environmental impact. The use of anti-bacterial products mainly affects ecotoxicity, which is an environmental issue that has so far only rarely been included in LCAs relating to fish products.

Many production processes yield more than one product. Many feed ingredients used in aquaculture, for example, are co-products from agricultural production (rice bran, fisheries bycatch). In the case of fisheries, filleting yields fillet and fish waste that can be used as feed and other products. Such cases are called multiple-output situations. In these situations, the environmental impact of the production system or process has to be allocated to the various outputs. In other words, the environmental impact related to the production of rice is allocated to multiple outputs, including rice grain, rice bran and rice straw. The environmental impact related to fishing is allocated to the marketable product (fillet) and the fish waste.

There are three main allocation methods (ISO, 2006): economic allocation, physical allocation (e.g. mass or energy allocation) and system expansion (see Table 2.1). In the case of mass or energy allocation, the environmental impact of a production system or process is allocated to its multiple outputs based on their relative mass (or energy), whereas in economic allocation the basis is their relative economic value. LCA results based on different methods of allocation cannot be compared directly. In this chapter we chose mass allocation because physical allocation was the most common allocation method used in the reviewed articles (see Table 2.1).

Most reviewed articles included only energy use or global warming in their LCA. To assess the impact on global warming of the production of a specific product, the studies we reviewed quantified emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Carbon dioxide is mainly released during the combustion of fossil fuels to power machinery, during fishing or industrial processes. Methane is inadvertently released during fossil fuel extraction and refining. Nitrous oxide is released during microbial transformation of nitrogen in the soil or in manure (i.e. nitrification of NH_4^+ into NO_3 and incomplete denitrification of NO_3 into N_2) as well as during nitrate fertiliser production.

In all studies, CO_2, CH_4, and N_2O emissions were summed up based on their equivalence factor in terms of CO_2 equivalents (100-year time horizon): 1 for CO_2, 25 for CH_4, and 298 for N_2O. This enables a valid comparison of the global warming potential (GWP) across studies. Similarly, in all studies energy use related to production and use of fossil fuels was summarised based on MJ.

Not all studies addressed eutrophication and acidification; only a few studies assessed land use.

As plaice, cod, salmon, tilapia and pangasius were the focus species of this research, we only included thirteen systems in the further research. The Ellingsen and Aanondsen study (2006) was not included because they based their article on the data by Thrane (2006). We included the only LCA of a recirculation aquaculture system (RAS) (Ayer and Tyedmers, 2009), which evaluated char, to demonstrate the strengths and weaknesses of RASs.

Table 2.1 Characteristics of 15 studies on the life cycle assessment of fish products originating from fisheries and aquaculture

				Environmental issues considered					Nr in
Reference	**Country and system**	**Species**	**Allocation**	**energy use**	**global**	**eutrophication**	**acidification**	**land use**	**this study**
Fisheries									
Winther *et al.* (2009)	NO-country average	Cod	mass	+	+				1
Winther *et al.* (2009)	NO-country average	Saithe	mass	+	+				
Winther *et al.* (2009)	NO-country average	Haddock	mass	+	+				
Winther *et al.* (2009)	NO-country average	Herring	mass	+	+				
Winther *et al.* (2009)	NO-country average	Mackerel	mass	+	+				
Ziegler and Hanson (2003)	SE-gillnet	Cod	mass/econ	+					2
Ziegler and Hanson (2003)	SE-trawler	Cod	mass/econ	+					3
Thrane (2006) in appendix	DK-country average	Cod	System expansion		+		+		4

DK=Denmark, NL=The Netherlands; NO=Norway; GR= Greece; CA=Canada; CI=Chile; ES= Spain; FR=France; UK=United Kingdom; ID = Indonesia; FI=Finland; SE=Sweden.

[1] For feed energy allocation, for output (if necessary) system expansion.

[2] For fishery mass allocation, for others economic allocation.

Table 2.1 (continued)	**Characteristics of 15 studies about life cycle assessment of fish products originating from fisheries and aquaculture**								
				Environmental issues considered					**Nr in**
Reference	**Country and system**	**Species**	**Allocation**	**energy use**	**global**	**eutrophi-cation**	**acidifi-cation**	**land use**	**this study**
Thrane (2006)	DK-country average	Flatfish (Plaice)	System expansion		+		+		5
Ellingsen and Aanondsen (2006)	NO-trawler	Cod	mass [2]	+					
Vásquez *et al.* (2010)	ES-bottom trawler	Horse Mackerel	mass/econ		+	+			
Vásquez *et al.* (2010)	ES-purse Seiner	Horse Mackerel	mass/econ		+	+			
Iribarren *et al.* (2011)	ES- trawler	Horse Mackerel	economic		+				
Iribarren *et al.* (2011)	ES-seiner	Horse Mackerel	economic		+				
Iribarren *et al.* (2011)	ES-trawler	Mackerel	economic		+				
Iribarren *et al.* (2011)	ES-seiner	Mackerel	economic		+				
Iribarren *et al.* (2011)	ES-trawler	Hake	economic		+				
Aquaculture									
Winther *et al.* (2009)	NO	Salmon	mass	+	+				6
Pelletier *et al.* (2009)	NO-Country average	Salmon	energy	+	+	+	+		7
Pelletier *et al.* (2009)	UK-Country average	Salmon	energy	+	+	+	+		

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Table 2.1 (continued)	**Characteristics of 15 studies about life cycle assessment of fish products originating from fisheries and aquaculture**								
				Environmental issues considered					**Nr in**
Reference	**Country and system**	**Species**	**Allocation**	**energy use**	**global**	**eutrophi-cation**	**acidifi-cation**	**land use**	**this study**
Pelletier *et al.* (2009)	CA-Country average	Salmon	energy	+	+	+	+		
Pelletier *et al.* (2009)	CI-Country average	Salmon	energy	+	+	+	+		8
Roque d'Orbcastel *et al.* (2009)	FI-flow through	Trout	system expansion	+	+	+	+	+	
Roque d'Orbcastel *et al.* (2009)	FI-Recir-culation	Trout	system expansion	+	+	+	+	+	
Ayer and Tyedmers (2009)	CA-Marine Net pen	Salmon	energy [1]	+	+	+	+		9
Ayer and Tyedmers (2009)	CA-Marine floating bag	Salmon	energy [1]	+	+	+	+		
Ayer and Tyedmers (2009)	CA-Flow flow through	Salmon	energy [1]	+	+	+	+		
Ayer and Tyedmers (2009)	CA-Recir-culation	Char	energy [1]	+	+	+	+		10
Aubin *et al.* (2006)	FR-Recir-culation	Turbot	economic	+	+	+	+		
Aubin *et al.* (2009)	GR-Sea cages	Sea-bass	economic	+	+	+	+		
Ellingsen and Aanondsen (2006)	NO	Salmon	economic	+					

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Table 2.1 (continued)	**Characteristics of 15 studies about life cycle assessment of fish products originating from fisheries and aquaculture**								
				Environmental issues considered					**Nr in**
Reference	**Country and system**	**Species**	**Allocation**	**energy use**	**global**	**eutrophi-cation**	**acidifi-cation**	**land use**	**this study**
Grönroos *et al.* (2006)	FI-Net cages	Trout	mass	+	+	+	+		
Pelletier and Tyedmers (2010)	ID-Lake-based	Tilapia	energy	+	+	+	+		11
Pelletier and Tyedmers (2010)	ID-Pond-based	Tilapia	energy	+	+	+	+		12
Bosma *et al.* (2011)	VN	Pangasius (Striped Catfish)	Mass	+	+	+	+		13

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[1] For feed energy allocation, for output (if necessary) system expansion.
[2] For fishery mass allocation, for others economic allocation.

To enable a comparison of eutrophication (EP), acidification potential (AP) and land use of plaice and cod with salmon, tilapia and pangasius, we used the following approach:

1. We deduced technical parameters from the articles reviewed (1-13 in Table 2.1), such as feed conversion, diet composition, origin of feed ingredients, energy requirement for feed processing or fish farming, etc.
2. We predicted the global warming potential of the diet by combining knowledge on technical parameters with Ecoinvent data 2.2. Ecoinvent data 2.2 allowed us to compute the GWP for each feed ingredient. If recent yield data were not available in Ecoinvent 2.2, we used production data from FAO (http://faostat.fao.org/default.aspx) for the countries concerned, averaged for the period 2005 to 2007. In addition, the energy requirements for the production of fishmeal were based on Schau *et al.* (2009).
3. We validated our predictions of GWP per kg of fillet by comparing them with the original results as published by the authors (see Table 2.2). Difference between published GWP and calculated GWP averaged 7.2% (range from 1-18%).

4. We combined technical parameters about diet composition with Ecoinvent data to assess the EP, AP and land use of each feed ingredient.
5. To determine the EP and AP per kg of fish fillet, we also assessed emissions of eutrophying elements (nitrate [NO_3^-] to water, phosphate [PO_4^{3-}] to water, and ammonia [NH_3] to air) and acidifying elements (NH_3) at the aquacultural farm. For each farm, we computed a farm-gate nitrogen (N) and phosphorus (P) loss as the difference between the NP in feed and the NP retained in fish. Subsequently, we assumed that about 13% of this farm N loss was NH_3 emission, and 87% was lost as NO_3^- to water (Gross *et al.*, 2000), where the farm P loss was assumed to fully leach as PO_4^{3-} to water.
6. To determine land use, we combined knowledge of technical parameters with Ecoinvent data 2.2. Ecoinvent data 2.2 allowed us to compute the land use for each feed ingredient. If recent yield data were not available in Ecoinvent 2.2, we used production data from FAO (http://faostat.fao.org/default.aspx) for the countries concerned, averaged for the period 2005 to 2007. Land use computation is only relevant for aquaculture.

To assess the EP along the entire life cycle, we added all emissions of nitrate (NO_3^-) to water, phosphate (PO_4^{3-}) to water, nitrogen oxide (NO_x) to air, and ammonia (NH_3) to air, based on their equivalence factor in terms of nitrate: 1 for nitrate, 10.45 for phosphate, 1.35 for NO_x and 3.64 for NH_3. To assess the AP, we added emissions of sulphur dioxide (SO_2), NO_x, and NH_3, based on their equivalence factor in terms of sulphur dioxide: 1 for SO_2, 0.7 for NO_x and 1.88 for NH_3.

Table 2.2 **Comparison of GWP (kg of CO_2-eq/kg of fillet) as published in different articles with our own computations**

Diet	Published (P)	Our computation (O)	O/P (in %)
Salmon NO (6)	2,160	2,063	95.5
Salmon NO (7)	1,790	1,518	84.8
Salmon CI (8)	2,300	2,123	92.3
Salmon CA (9)	1,830	1,850	101.1
Tilapia Lake based ID (11)	1,520	1,249	82.2
Tilapia Pond based ID (12)	2,100	1,848	88.0
Pangasius VN (13)	4,743	4,576	96.5
Cod Fishing NO (1)	740	755	102.0

The procedure described above enabled a comparison of energy use and GWP among published studies about cod, plaice, salmon, tilapia and pangasius, as well as EP, AP and land use.

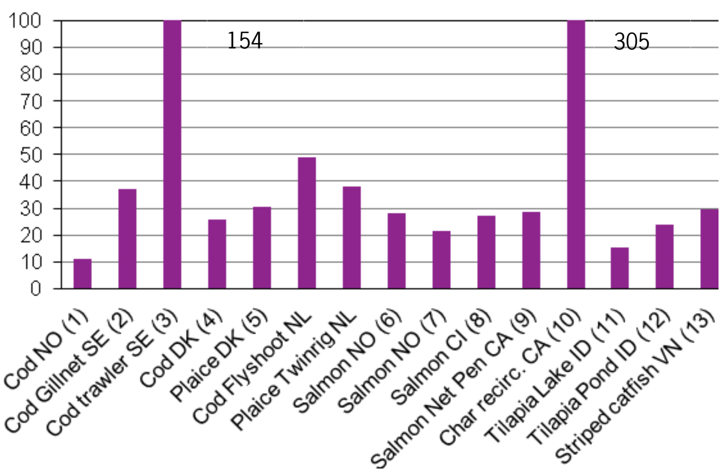
Using our own data, we also computed the energy use, GWP, AP and EP of two Dutch fishery-systems: cod caught by flyshoot and plaice caught by twinrig. Data about fossil fuel use were based on the average statistics for 2010 (LEI, Bedrijven-informatienet, 2010), i.e. 0.84 litre of fuel for 1 kg of landed plaice by twinrig and 1.08 litre of fuel per kg of landed cod by flyshoot.

2.2 Comparison of environmental impact

Energy use and global warming potential

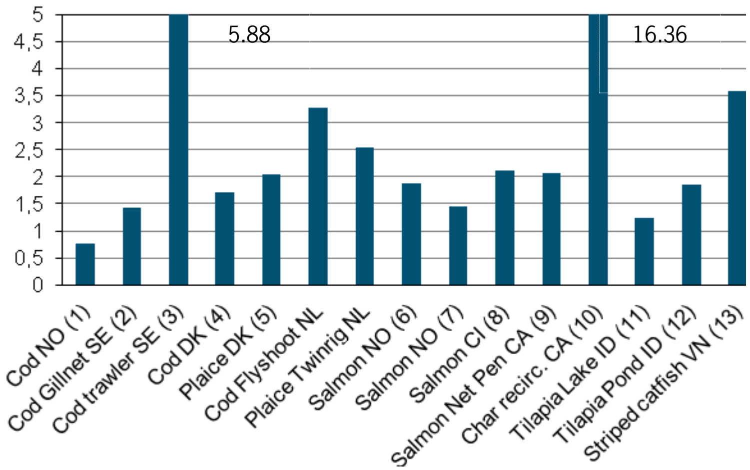
Figure 2.1 shows the results for energy use per kg of fillet for the thirteen published systems included in our analysis (number 1-13 in Table 2.1) and the two NL systems added. Energy use varied from 11 to 305 MJ per kg of fillet.

Figure 2.1 **Total fossil energy use of analysed systems (in MJ/kg of fillet)**



Similarly, results for the GWP per kg of fillet are presented in Figure 2.2. The GWP varied from about 0.7 to 16.4 CO_2-eq per kg of fillet.

Figure 2.2	Global Warming Potential of analysed systems (in kg of CO_2-eq/kg of fillet)



A comparison of Figures 2.1 and 2.2 shows that the GWP is determined to a great extent by the use of fossil fuels (CO_2-emission). This is because current LCA studies did not include N_2O emissions on the fish farm, which implies a systematic underestimation of GWP per kg of farmed fish. Although the amount of N_2O emitted can be low, because of the high equivalence factor (298) the influence on the GWP can be substantial. The relative influence of this omission is difficult to assess without further research.

The GWP of pangasius is relatively high compared to the energy use of this system. This is caused by the fact that the feed in this system contains about 20% rice products. The paddy fields, where the rice is cultivated, emit about 1,270 kg methane ha^{-1} yr^{-1} (IPCC, 2006).

Cod fishing with a trawler (3) resulted in a higher GWP and energy use per kg of wild-caught fish than cod fishing with a gillnet or flyshoot (2). The Swedish study that explored cod trawler fishing, however, used relatively old data (1999). Current trawler equipment might be more efficient, which might reduce the observed difference. Differences in available fish stocks can also influence the results. Cod and plaice fishing in the Netherlands resulted in a relatively higher energy use (and related GWP) as compared to Norway or Denmark. It should be noted that Dutch fishers generally do not specifically fish for cod. This takes place incidentally but it can be more energy efficient. This makes it difficult to compare Dutch cod fishers with their counterparts in other countries such as Sweden.

Energy use (and the related GWP) in aquaculture was highest for char recirculation systems (i.e. 305 MJ/kg of fillet). This is not due to the species, but is partly inherent in recirculation aquaculture systems (RAS). RAS energy requirements are high because the water is filtered and recycled. New water is added to the system only to make up for splash-out and evaporation, and for the water used to flush out waste materials. However, RAS energy requirements have improved over the last couple of years and will continue to improve (Martins, 2010).

Based on current cradle-to-farm gate LCAs, we cannot conclude that wild-caught fish has a higher or lower energy use or GWP per kg of fillet than farmed fish. There were large differences among individual fishing techniques and aquacultural systems, and in itself this offers potential for improvement. We also noticed that the current LCAs of farmed fish did not include N_2O emissions on the fish farm, which might have resulted in an underestimation of GWP per kg of fillet.

Tables 2.3 and 2.4 contain the results of fossil energy use and GWP related to processing and transport, expressed per kg of fillet. The energy requirements for processing and transport were based on Ecoinvent data 2.2, except for the energy requirements for processing in Vietnam, which were based on Bosma *et al.* (2011). Estimates for processing vary from 0.5 to about 5 MJ per kg of fillet, and 0.03 to 0.93 GWP per kg of fillet. The differences result from differences in the types of energy sources used in different counties. Sweden and Norway, for example, use renewable energy sources, such as wind or hydropower, to a relatively large extent.

Estimates for transport varied from 0.8-2.8 MJ or 0.03 to 0.15 GWP per kg of fillet. Note that transport by plane (e.g. from Iceland) requires much more energy and 49.6 MJ or 3.36 GWP per kg of fillet.

Table 2.3	**Overview of reported fossil energy use and global warming potential (GWP) for processing and freezing in reviewed articles (values per kg of fillet)**		
Reference	**Process**	**Energy use**	**GWP**
Thrane	Processing (including freezing) of plaice	2.6 MJ of electricity 1.5 MJ of heat	0.10
Thrane	Processing (including freezing) of cod	3.8 MJ of electricity 2.3 MJ of heat	0.15
Winther	Filleting of salmon	2.8 MJ of electricity	0.15
Winther	Freezing of salmon	0.5 MJ of electricity	0.03
Den Heijer a)	Processing (inclusive freezing) of pangasius in Vietnam	4.9 MJ of electricity	0.93

a) Personal communication based on an anonymous pangasius farm in Vietnam.

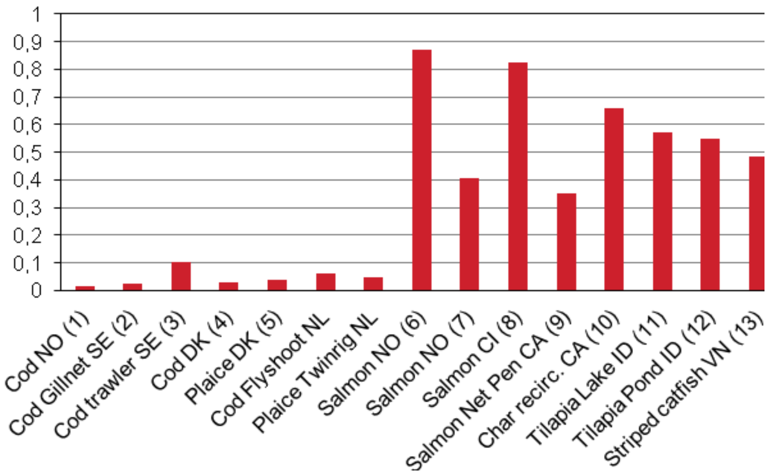
Table 2.4	**Transport distances, energy costs and corresponding global warming potential for transport of 1 kg of product to Rotterdam**			
From	**Distance (km)**	**Transport**	**Energy (MJ)**	**GWP kg CO_2-eq**
Jakarta/Indonesia	15,748	boat	2.63	0.17
Ho Chi Min/Vietnam	16,444	boat	2.75	0.18
Trondheim/Norway	1,307	truck	2.38	0.14
Esbjerg/Denmark	463	truck	0.84	0.05
Vancouver/Canada	16,422	boat	2.75	0.18
Reykjavik/Iceland	2,042	plane	49.6	3.36

For boat transport: www.searates.com; For others www.geobytes.com

Eutrophication and acidification potential

Figure 2.3 shows the EP per kg of fillet for the thirteen published systems included in our analyses (numbers 1-13 in Table 2.1) and the two NL systems added.

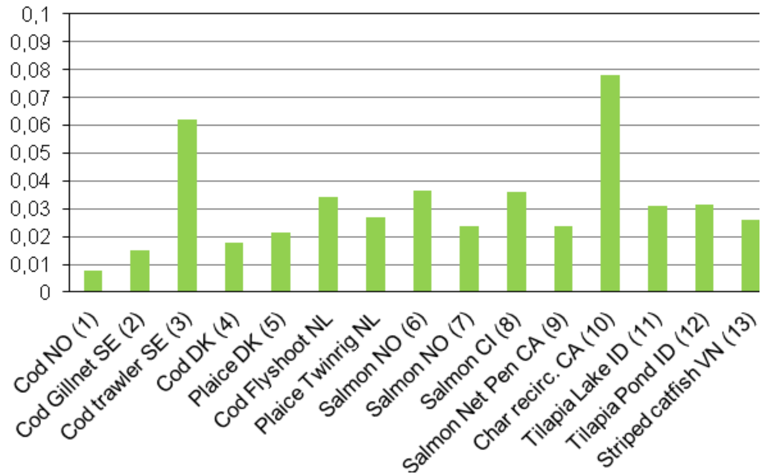
Figure 2.3	Eutrophication potential of analysed systems (in kg of NO_3--eq/kg of fillet)



The EP of wild-caught fish is very low compared to the EP of farmed fish. The EP in aquaculture results from emissions of NH_3 and leaching of NO_3^- during the cultivation of feed ingredients and during fish farming. Except for RASs, on average 86% (range 79%-93%) of the EP in aquaculture originated from on-farm emissions of NH_3 and leaching of NO_3^-. In RASs, however, the emission of NH_3 is almost zero (Schneider et al., 2007).

Figure 2.4 shows the AP per kg of fillet for the thirteen published systems included in our analyses (numbers 1-13 in Table 2.1) and the two NL systems added.

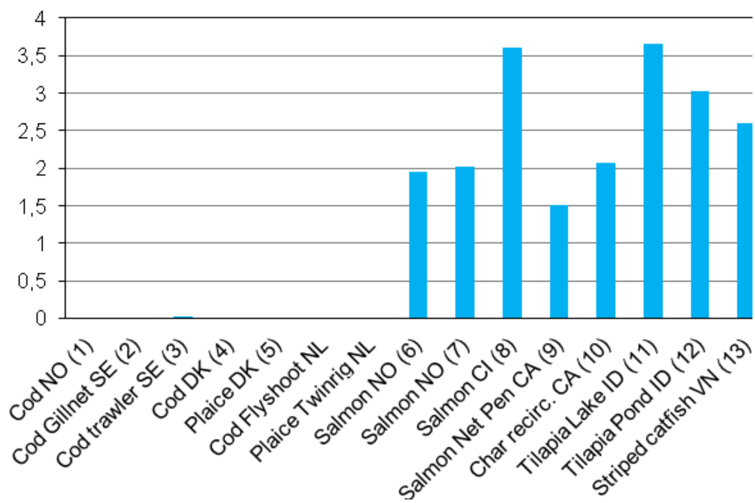
Figure 2.4 | **Acidification potential of analysed systems (in kg of SO_2-eq/kg of fillet)**



The AP mainly resulted from two aspects: (1) emissions of SO_2 related to the burning of fossil fuel, and (2) ammonia emissions during fish farming. In the aquaculture systems (except for RASs), on average 51% (range 33%-64%) of the AP originates from the ammonia losses from the pond. Based on a cradle-to-farm gate analysis, we cannot conclude that wild-caught fish has a higher or lower AP per kg of fillet than farmed fish. There were significant differences among individual fishing techniques and among the aquacultural systems. This shows that there is potential for improvement.

Figure 2.5 shows the land use per kg of fillet for the thirteen published systems included in our analyses (numbers 1-13 in Table 2.1) and the two NL systems added.

Figure 2.5	Land use of analysed systems (in m²/kg of fillet)



The land used by wild-caught fishing is used for the production of fuels. In aquaculture a substantial amount of land is required to produce fish fillets. This land is required to cultivate feed ingredients. Differences in land use among different studies can be explained by differences in diet composition and feed conversion rate (kg of feed/kg of fish fillet). Diets with a higher proportion of fishmeal or fish oil have a lower land use. In addition, a higher feed conversion will increase the land requirement per kg of fillet (11 vs 12).

2.3 Conclusions

The following conclusions can be drawn from the LCA analysis:

- Current LCA results do not show a significant difference ($p=0.80$) in energy use or global warming potential per kg of plaice and cod or salmon, tilapia and pangasius. Although there is some difference in the mean values, there is a great deal of variance in the data, resulting in insignificance.
- The average GWP of aquaculture (excluding one extremely high measurement) is 2.03. This equals the use of 0.67 l fuel per kg of landed fish. Current figures for wild-caught fish in the Netherlands are 0.84 l/kg for plaice and 1.08 l/kg for cod.

- The GWP of pangasius is strongly influenced by the amount of rice products included in the feed.
- Current estimates of the GWP of farmed salmon, tilapia and pagasius might be underestimated, because on-farm emissions of N_2O (greenhouse gas with a significant impact) are not included.
- The eutrophication potential of wild-caught cod or plaice is lower than the eutrophication potential of farmed salmon or tilapia ($p<0.0001$).
- Current LCA results do not show a significant difference in acidification potential per kg of wild-caught cod and plaice or farmed salmon or tilapia ($p=0.33$).
- The land use is significant in aquaculture. This land is used to cultivate feed ingredients ($p<0.0001$).
- The land use for wild-caught fishing only includes land used for the extraction and production of energy. Figures are too low to be measured. Wild-caught fishing often has an impact on the ecosystems in the sea. The biodiversity is influenced by disruptions to the seabed and by the exploitation of fish resources (both target fish and bycatch and discards). It is difficult to quantify this and weigh it against other impact categories (Thrane, 2004).

3 Environmental impact of animal products

3.1 Introduction

A comparison of the environmental impact of North Sea fish with that of imported aquaculture is not the only relevant comparison that can be made. Fish also faces competition from other protein sources such as pork and chicken. In determining the qualities of North Sea fish, it is therefore important to place environmental impact within a broader picture. In this chapter, we report on a life cycle assessment on pork, chicken and beef.

The production of meat involves a number of sustainability issues. Meat production is a driving force behind the greenhouse gas emissions. As much as 12% of the emissions of greenhouse gases worldwide originate from livestock farming. In the Netherlands, greenhouse gas emissions from livestock farming account for around 11% of the total, while the European average is around 8%[1]. The emissions level in the Netherlands is higher than the European average because the Dutch livestock farming sector is relatively large (Netherlands Environmental Assessment Agency [PBL], 2009). Emissions of greenhouse gases in livestock farming arise on the one hand due to the use of fossil fuels and on the other hand due to deforestation to create farmland. The animal manure also results in the acidification and contamination of groundwater and surface water (Dolman et al., 2010). Lastly, it contributes to a reduction in biodiversity as large areas of woodland are converted into palm oil and soya plantations (Kamphuis et al., 2011).

3.2 Life-Cycle Analysis

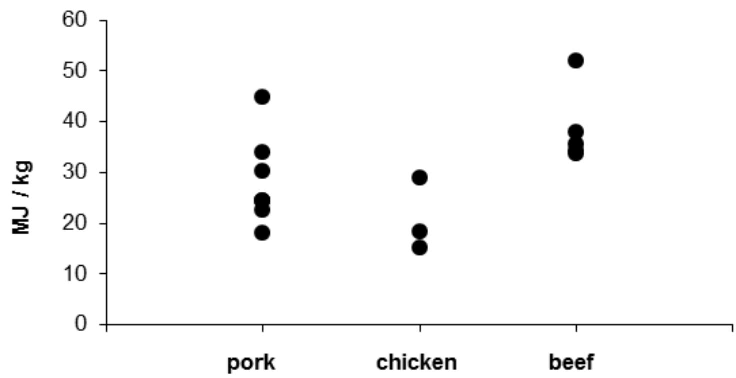
As in chapter 2, the calculation of the environmental impact as a functional unit is based on the impact per kilogram of the product. However, a different method of allocating the environmental impact to the multiple outputs is used. In this chapter, economic allocation is used. The figures have been taken from the publication by De Vries & De Boer (2010), who carried out a meta-analysis of the environmental impact of various products from the livestock farming sector.

[1] Greenhouse gas emission figures are based on data from the Edgar 4.0 database, which makes use of IPCC Guidelines.

In their study, the researchers made use of LCA literature from all over the world. The results therefore relate not to the Dutch livestock sector but to the global livestock sector. On the basis of the available data, the environmental impact of livestock farming is expressed below in three impact categories: energy consumption, global warming potential (GWP) and land usage.

Energy consumption
Approximately 43 MJ of energy was required for the production of one kilogram of beef (see figure 3.1). That is more than double the amount of energy consumed for the production of a kilogram of pork or chicken. Energy consumed in the livestock sector is used for matters including: the production and transport of animal feed and the production and use of fuels (diesel, gas) and electricity at the farm (Thomassen et al., 2009).

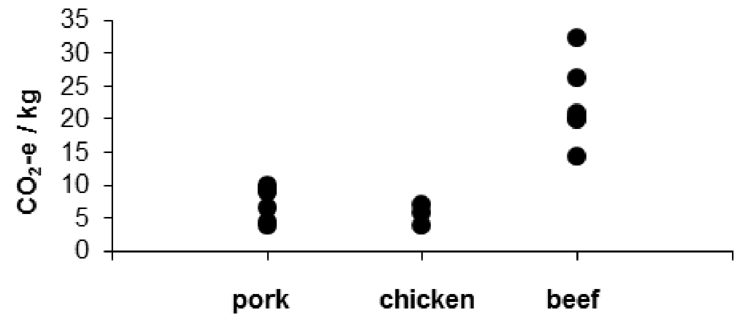
Figure 3.1 **Energy consumption in MJ/kg product**



Source: De Vries en De Boer (2010).

Climate change
Figure 3.2 shows the potential climate change (GWP) for three products from the livestock sector, measured in CO_2-equivalents per kilogram of the product. GWP resulting from livestock farming could be a consequence of emissions released by manure and emissions caused by the transportation of feed, amongst other things (Thomassen et al., 2009). Once again, it is beef that potentially has the greatest impact on GWP, followed by pork and chicken.

Figure 3.2 **Climate change, in CO2-eq/kg product**

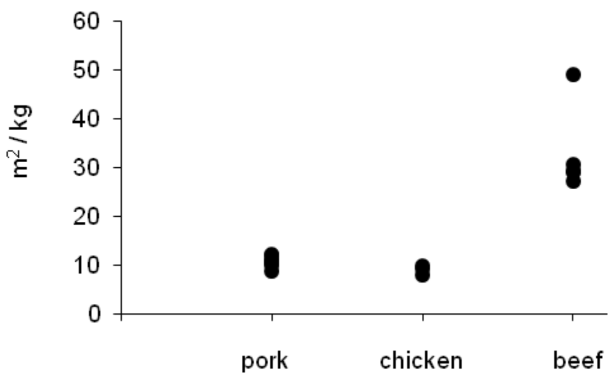


Source: De Vries en De Boer (2010).

Land usage

As shown in figure 3.3, the production of beef requires the most land: between 27 and 49 m^2 land per kilogram of meat. The amount of land used for the production of pork (8.9-12.1 m^2 of land per kilogram of meat) and chicken (8.1-9.9 m^2 of land per kilogram of meat) is considerably less.

Figure 3.3 **Land usage, in m2/kg product**



Source: De Vries en De Boer (2010).

3.3 Conclusions

This chapter maps out the environmental impact of three different livestock-farming products on the basis of a review of the literature on LCA studies. The environmental impact is measured by means of three categories: energy consumption, global warming potential and land usage. The comparison of livestock-farming products demonstrates that beef production results in the greatest environmental impact in three impact categories, in terms of land usage, energy consumption and global warming potential.

The second objective of this chapter is to compare the environmental impact of North Sea whitefish with that of other protein sources. Table 3.2 compares the results of the LCA of plaice and cod with the results of the LCA of beef, pork and chicken. Some comments will aid in understanding this table.

In Chapter 2, the LCA is based on mass allocation. To enable a comparison with the LCA data on meat, we have recalculated the environmental impact of fisheries using economic allocation. As discussed in Chapter 2, in LCAs the total environmental impact is allocated to the various products produced (in the case of fish: fillet and fish waste). This can be done on the basis of mass or value (economic allocation). Fish waste has a low value but a high mass. When economic allocation is used, a small percentage of the total environmental impact is allocated to the fish waste. When mass allocation is used, a much higher percentage is allocated to the fish waste.

The LCA in Chapter 2 used mass allocation. The LCA data on beef, pork and chicken are based on economic allocation. In recalculating the environmental impact of plaice and cod from mass allocation to economic allocation, we have used the following figures (personal communication with Jaczon). Note that this is the value of fillet for the first seller, not for retail. An overview of factors used in recalculation is given in Table 3.1.

Table 3.1	**Factors used to recalculate environmental impact of fisheries, from mass allocation to economic allocation**
Indicator	**Factor**
% of fillet (plaice)	40%
% of fillet (cod)	45%
Value of fish waste	0.11
Value of plaice (fillet)	4.14
Value of cod (fillet)	7.09

We have excluded foreign studies on fisheries because the data required to recalculate was not available.

Table 3.2	**Comparing energy use and GWP of plaice, cod, pork, chicken and beef**	
	Energy use (MJ/kg of fillet)	**GWP (kg of CO_2-eq/kg of fillet)**
Cod flyshoot (NL)	106	7.2
Plaice twinrig (NL)	91	6
Pork	18-45	3.9-10
Chicken	15-29	3.7-6.9
Beef	34-52	14-32

The following conclusions can be drawn from this overview:

- The energy use for plaice and cod is higher than the energy use for pork, chicken or beef.
- The global warming potential of plaice and cod is in the same range as that of pork and chicken. Beef has a higher GWP. This difference can be explained by the non-CO_2 greenhouse gas emissions from animals and manure.

4 Expected improvements to environmental performance

4.1 Introduction

In the previous chapters, an LCA was used to determine the overall impact of both wild-caught fishing and aquaculture on the environment. In addition, we have compared the life cycle impact of fish with the impact of pork, chicken and beef.

In this chapter, we take these analyses as our point of departure and look at some of the predicted developments in the fisheries sector. Our objective is to analyse how innovations in fishing and fish-farming methods can affect the life cycle impact of wild-caught fishing and aquaculture.

4.2 Scope

The future of Dutch fisheries is the subject of various studies. In the LEI report 'A sustainable future for Dutch fisheries' (*Een duurzame toekomst voor de Nederlandse visserij*) by Hoefnagel *et al*. (2011), scenarios are discussed for the long term future of the sector. The defining characteristics of the different scenarios are: (1) the intensity of fishing (high vs low) and (2) the balance between nature and human interest (nature vs human). The resulting four scenarios were analysed, with a focus on people, planet and profit.

In the analysis of Hoefnagel *et al*. long-term changes are taken into account and the scenarios are compared by reference to macro-economic, social, and governance criteria. In this study, we focus on the short-term changes and analyse how these might change the LCA of wild-caught fishing and aquaculture within the near future. The long-term scenarios offer some insights to start this analysis. They are built upon expectations for future changes. We can take into account some of the technological changes, or innovations, that are expected for the near future. Given the short-term focus of this study, we have decided to leave out the long-term socio-economic changes (e.g. changing food prices) and the changes in governance (such as changing quotas).

In this chapter, we explore the potential of these innovations in greater detail and analyse how the implementation of innovations can affect the life cycle impact of wild-caught fishing and aquaculture. The following five developments are analysed in more detail:

For plaice and cod:

1. Higher fish stocks, which means that less energy is required to catch the same amount.
2. Increasing fuel efficiency through changes in fishing methods.
3. Changing fuel mix, with a greater use of biofuels.

For aquaculture, improving current production systems by:

1. Better feed conversion ratio.
2. The use of alternative feed sources.

Given the complexity of life cycle assessments, the cross-relations between the sorts of environmental impact, and the lack of validated data, we cannot accurately recalculate the LCA with these innovations in mind. We can, however, argue how innovations would change the impact, focussing on the direction of change (higher or lower impact) and the magnitude (small, medium, large).

4.3 Increasing fish stocks

Fish stocks constantly change under the influence of several factors, including climate change, changes in ecosystems, and changing fishery conditions. Wageningen UR, the Netherlands Environmental Assessment Agency (PBL) and Statistics Netherlands (CBS) disclose information on the state of the environment and natural resources through the website compendiumvoordeleefomgeving.nl. The data available on this website includes information about the development of fish stock over time.

If we look at the fish stock of North Sea cod and plaice, the following picture emerges. Cod stock decreased drastically between the early 1970s (275 million kg) and 2006 (29 million kg) but has increased since then, up to 55 million kg in 2011. Ecological limits are set at 70 million kg (critical limit) and 150 million kg (precautionary limit). The changes in plaice stock are quite different. The lowest plaice stocks were reported in 1996 (181 million kg). Since 2005, plaice stocks have increased sharply, up to 523 million kg in 2011. This exceeds the precautionary limit (230 million kg).

Why are increasing fish stocks important for the LCA of wild-caught fishing? Larger stocks mean that fishermen spend less time and fewer resources to catch equal amounts of fish. Consequently, the energy use per kg of fillet decreases. As stated in 4.2, we do not take the option of larger quotas into account. Whether or not fishermen are allowed to catch more fish by increasing quotas is a political decision.

We have analysed the reported data in more detail and investigated the relative growth in fish stock per year and over a five-year period. An overview of the results is presented in the following table.

Table 4.1 **Changes in fish stock over one-year and five-year periods**

	Cod		Plaice	
	% change/1 year	**% change/5 year**	**% change/1 year**	**% change/5 year**
2007	27.6	-15.9	1.6	29.9
2008	13.5	5.0	38.3	57.0
2009	21.4	45.7	6.9	82.9
2010	3.9	60.9	19.4	85.9
2011	3.8	89.7	13.4	103.8

Derived from *Planbureau voor de leefomgeving et al.* (2011).

In the LCA in Chapter 2, technical parameters for energy use, global warming, acidification and eutrophication were deducted from scientific papers published between 2003 and 2011. As Table 4.1 shows, the reported fish stocks for cod and plaice have more or less doubled in the five years between 2007 and 2011. To estimate the effect of growing fish stocks on total energy consumption, it is necessary to make certain assumptions. First of all, it is important to note that the total energy use is the sum of the energy used when fishing and the energy used by trawlers when travelling to the fishing grounds. Secondly, it is an oversimplification to state that twice the amount of fish would mean fishermen need to spend only half the time and energy to catch equal amounts. Table 4.2 shows how increasing fish stocks affect the LCA outcome.

The total population size does not include information on the age distribution within the population. This also influences the revenues of fishermen: when populations are relatively young, revenues are lower.

Table 4.2	LCA impact of higher fish stocks	
	Effect of higher fish stocks	
Indicator	**Effect**	**Impact**
Energy use	Higher fish stock means less energy consumption per kg of fish caught.	↓
GWP	Higher fish stock means less fuel consumption per kg of fish caught. Fuel consumption is linearly related to GWP. A 20% reduction in fuel consumption means that GWP is reduced by 20%.	↓
EP	Higher fish stock means less fuel consumption per kg of fish caught. Fuel consumption is linearly related to eutrophication.	↓
AP	Higher fish stock means less fuel consumption per kg of fish caught. Fuel consumption is linearly related to acidification.	↓
Land use	Higher fish stock means less fuel consumption per kg of fish caught. Fuel consumption is linearly related to land use.	↓

In the next paragraph we examine fuel savings in more detail and analyse how this affects the comparison of GWP between wild-caught fishing and aquaculture.

4.4 Increasing fuel efficiency

Fuel use constitutes one of the greatest expenses for wild fisheries. For this reason, fuel prices are strongly related to the total income, and changes in fuel prices directly affect income, for better (as seen in the year 2009 compared with 2008) or worse (as seen in 2010 compared with 2009). It is predicted that fuel prices will increase in the future, a result of increased competition for fossil fuels and depleting resources (International Energy Agency, 2011).

Given the impact of fuel prices on income, fishers have sought for ways to improve the fuel efficiency of their fleets. One of the Fisheries Knowledge Networks (*'Slim ondernemen in de Platvisvisserij'*, 'Clever Entrepreneurship in Flatfish fishery') examined options for reducing fuel use for beam trawlers in greater detail. The results of this study are published in the leaflet *Hoezo dure gasolie?* ("What do you mean, expensive gas oil?") (*Kenniskring Slim Ondernemen in de Platvisvisserij*, 2009).

In light of these options for reducing fuel use, it is clear that fuel use is largely determined by the method used for fishing. The beam trawl method requires a great deal of energy and the use of alternative methods results in much lower fuel consumption. It is estimated that the use of a SumWing can result in savings of 10-20%. In *'Visserij in cijfers, 2010'* it is stated that an average beam trawler (a vessel measuring around 40 metres) can save up to 300 tonnes of fuel by using SumWings and still catch equal amounts (Taal *et al.*, 2010). The use of the pulse trawl method is expected to reduce fuel consumption even more: a shift to pulse trawling can, with the current state of technology, reduce energy use by 45 to 60% (compared to beam trawlers in 2008), depending on the type of vessel and engine (*Kenniskringen Puls en Sumwing* and *Slim Ondernemen in de Platvisvisserij*, 2009).

Other options for reducing fuel use cannot compete with the large reduction brought about by a change in fishing methods. However, fuel consumption can be reduced by taking relatively easy measures that require little or no investments. Examples of such measures include using lighter nets, reducing speed while fishing, and using cruise control and fuel consumption instruments. Each of these measures can result in a reduction in fuel use of 1-5%. Although it is difficult to calculate these reductions precisely, a total reduction in fuel consumption of 10% seems reasonable as a result of these measures. Table 4.3 illustrates how increased fuel efficiency affects LCA outcome.

Table 4.3	**LCA impact of increased fuel efficiency**	
	Effect of reduced fuel consumption	
Indicator	**Effect**	**Impact**
Energy use	Fuel consumption is linearly related to energy use	↓
GWP	Fuel consumption is linearly related to GWP	↓
EP	Fuel consumption is linearly related to eutrophication	↓
AP	Fuel consumption is linearly related to acidification	↓
Land use	Fuel consumption is linearly related to land use	↓

For wild-caught fishing, fuel consumption is linearly related to the environmental indicators GWP, eutrophication and acidification. A 20% reduction of fuel consumption means that GWP, eutrophication and acidification are all reduced by 20%.

4.5 Changes in the fuel mix

The use of sustainable fuels, or biofuels, is another way to reduce CO_2 emissions and fuel use by fishers. Fossil fuels are used at present, and replacing them with alternative fuels could reduce the GWP of fisheries. The use of biofuels leads to a net reduction of a number of emissions, particularly carbon dioxide emissions, as CO_2 is extracted from the air when natural resources are grown.

There are methods for the production of biofuels.

- The first, and currently most common, option is to produce biofuels from plant materials derived from plants such as oil palms, *Jatropha* and sugar cane.
- The second option is to use animal products for the production of aquatic biofuels (FAO, 2011). This option is currently being researched by various institutes and corporations, as it would make it possible to produce biofuels from what is currently redundant catch. This production could be carried out on shore or even on board.

Although CO_2 is emitted by the combustion of these fuels, it is common to attribute no GWP to these fuels. The reason for this is that CO_2 is captured during the production of these fuels. If biofuels are produced from plant material, land use increases. The use of alternative fuel sources derived from plant material means higher impact on the EP and AP because use and production of these fuels have an impact on these indicators. Table 4.4 illustrates how the use of alternative fuel affects the LCA outcome.

Table 4.4	**LCA impact of alternative fuel**		
Effect of alternative fuels			
Indicator	**Effect**	**Impact (plant based)**	**Impact (fish based)**
Energy use	A shift to alternative fuels does not alter energy use but reduced use of fossil energy reduces LCA dramatically	↓	↓
GWP	Renewable alternative fuels have lower GWP	↓	↓
EP	Production of alternative fuels increases eutrophication	↑	=
AP	Production of alternative fuels increases acidification	↑	=
Land use	Land is required to produce alternative fuels	↑	=

4.6 Improved feed conversion

One of the determinants of the environmental impact of aquaculture is the feed conversion rate (FCR). This describes how much feed is required to produce a fixed amount of fish. Improving the feed conversion rate is one way to reduce the total environmental impact of aquaculture. In the literature used for the LCA (see Chapter 2), the feed conversion rates for tilapia are generally around 1.7. The FCR for aquaculture salmon is reported to vary between 1.1 and 1.5 (Pelletier *et al.*, 2009). A great deal of research focuses on what feed conversion rate can be achieved. This would mean an immediate improvement in the economic and ecological performance of aquaculture. For tilapia, it is expected that FCR can be reduced to 1.2.[1] This requires a change in diet and earlier harvesting (meaning smaller fish). For salmon, feed conversion rates close to 1 are now reported.[2]

If we assume hypothetically that a better FCR means that less of the same feed is required, the environmental impact would logically decrease, albeit not linearly. The total environmental impact is also influenced by the energy used during production. If diets change, which is almost inevitable, net effects on the environment are more difficult to assess. Table 4.5 illustrates how improved feed conversion affects LCA outcome.

Table 4.5 LCA effect of improved feed conversion

	Effect of improved feed conversion ratio (no change in diet)	
Indicator	**Effect**	**Impact**
Energy use	Less feed required means less energy is used	↓
GWP	Lower energy use means lower GWP	↓
EP	Less feed required means less eutrophication takes place during feed production	↓
AP	Less feed required means less acidification takes place during feed production	↓
Land use	Less feed required means less land is required for the production of feed	↓

[1] www.aces.edu
[2] www.mainstreamcanada.ca

4.7 Alternative feed resources

Changes in diet in aquaculture is another way to reduce the life cycle environmental impact. The net benefits of such changes are not easily assessed. A change in diet will almost certainly affect the FCR and growth of fish. Therefore, we only give some indications on how changing diets might affect LCA.

From an examination of the literature on sustainable aquaculture and certification schemes for sustainable aquaculture, it appears that a reduction of the percentage fish oil is desirable. If we look at the LCA data, a reduction of fish oil use appears less favourable as it increases land use, eutrophication and acidification.

If we increase the amount of fish oil to a hypothetical 100%, the following picture emerges. Obviously, land use is reduced to nearly zero. Life cycle contributions to the EP and AP are also reduced, but energy use and GWP increase (more energy required to catch feed). Table 4.6 describes how the use of alternative feed sources affects the LCA.

Table 4.6 LCA effect of alternative feed sources

Effect of alternative feed resources			
Indicator	**Effect**	**Impact (plant based)**	**Impact (fish based)**
Energy use	Fuel consumption relates to the method of feed production	↓	↑
GWP	Global warming potential is determined by method of feed production	↓	↑
EP	Eutrophication is determined by method of feed production	↑	↓
AP	Acidification is determined by method of feed production	↑	↓
Land use	Land use potential is determined by method of feed production	↑	↓

It is not possible to give an easy assessment of the LCA for changing feed. The net changes in environmental impact differ greatly depending on the resources used for feed. The use of more aquatic resources (fish oil) would mean that land use is reduced, but would come with greater energy use and a higher GWP. Land-based products show a different picture, with higher land use but lower energy use. This could mean that the GWP would be lower; but if rice, for instance, is used as feed, the GWP will increase due to the methane emitted during rice production. Alternative feed sources such as bone meal (replacing fish meal) offer possibilities for improving environmental performance yet are not common practice (Fasakin, Serwata et al., 2005).

4.8 Analysis and conclusions

We have described various options for reducing the environmental impact of both wild-caught fishing and aquaculture. Table 4.7 summarises how these developments and innovations affect the life cycle environmental impact.

Table 4.7 Summary of effects on outcome of LCA

			Energy use	**GWP**	**EP**	**AP**	**Land use**
Wild-caught	Increased fish stock		↓	↓	↓	↓	=
	Reduced fuel consumption		↓	↓	↓	↓	=
	Alternative fuels	Plant-based	=	↓	↑	↑	↑
		Fish-based	=	↓	=	=	=
Aqua-culture	Improved FCR		↓	↓	↓	↓	↓
	Alternative feed sources	Plant-based	↓	↓	↑	↑	↑
		Fish-based	↑	↑	↓	↓	↓

In general, both the wild-caught sector and aquaculture can improve their environmental performance, but the effects of improvements in aquaculture do not seem to be as straightforward as in fisheries.

It is also apparent that some of the changes, such as a shift to using biofuels in the diet of aquaculture, come with pros and cons. Changing to plant-based feed or fuel results in greater land-use. The alternatives (use of fish oil for feed and use of biofuels) use more energy and have a higher GWP. For these indicators, we can only assess the direction of change with the information currently available. More information is needed to be able to state exactly how much reduction is achieved.

It is possible to make incremental changes in the efficiency of wild-caught fishing and aquaculture, and these changes would have only positive results. The life cycle impact of North Sea fishing is linearly related to fuel consumption. The LCA allows us to compare North Sea fishing with aquaculture and calculate the degree to which energy use should be reduced to achieve the same GWP as aquaculture.

The average GWP of aquaculture (excluding one extremely high measurement) is 2.03. This equals the use of 0.67 l fuel per kg of landed fish. Current figures as used in the LCA are for 0.84 l/kg for plaice and 1.08 l/kg for cod. To reduce fuel consumption to 0.67 l/kg, reductions of 20% (plaice) and 38% (cod) are required. As discussed in this chapter, new fishing methods and increased efficiency would make significant reduction possible.

The following conclusions can be drawn from this analysis:

- Predicted technological improvements offer possibilities for reducing the environmental impact of both wild-caught fishing and aquaculture.

Current developments in both fishing technology and fisheries management will most probably result in a significant reduction of the environmental impact of wild-caught whitefish in the Netherlands in the coming years.

- All technologies that reduce fuel use have a direct positive impact on the LCA.
- Other changes, such as a shift to biofuels or changes in the diet of aquaculture, all come with pros and cons. There is no easy win.
- The consequences of changing feed sources for aquaculture on the LCA are dependent on the source of feed (plant vs fish).

5 Conclusion and discussion

5.1 Introduction

The environmental impact of wild-caught North Sea plaice and cod is comparable with that of salmon, tilapia and pangasius from aquaculture, the most important import fish. Although plaice and cod catching requires more energy than meat production, the global warming potential (GWP) is comparable due to lower non-CO_2 greenhouse gas emissions. Expected technological innovations make it possible to significantly reduce the environmental impact of plaice and cod fishing.

These conclusions are the result of the different steps taken in this research. First, we focussed in detail on the environmental impact of North Sea plaice and cod, in comparison to imported salmon, tilapia and pangasius. The following main conclusions can be drawn from the LCA:

- Current LCA results do not show a significant difference ($p=0.80$) in energy use or global warming potential per kg of wild-caught cod and plaice or farmed salmon, tilapia and pangasius. Although there is some difference in the mean values, there is a great deal of variance in the data, resulting in insignificance.
- The eutrophication potential of wild-caught cod or plaice is lower than the eutrophication potential of farmed salmon or tilapia ($p<0.0001$).
- Current LCA results do not show a significant difference in acidification potential per kg of wild caught cod and plaice or farmed salmon or tilapia ($p=0.33$).
- The land use is significant in aquaculture. This land is used to cultivate feed ingredients ($p<0.0001$). The land use for wild-caught fishing only includes the land used for the extraction and production of energy. Figures are too low to be measured. Wild-caught fishing often has an impact on the ecosystems in the sea. The biodiversity is influenced by disruptions to the seabed and by the exploitation of fish resources (both target fish and bycatch and discards). It is difficult to quantify this and weigh it against other impact categories (Thrane 2004).

Subsequently, we compared the environmental impact of plaice and cod with the environmental impact of meat. From this analysis, we drew the following conclusions:

- The energy use for plaice and cod is higher than the energy use for pork, chicken and beef.
- The global warming potential of plaice and cod is in the same range as that of pork and chicken. Beef has a higher GWP. This difference can be explained by the non-CO_2 greenhouse gas emissions from animals and manure.

Thirdly, we investigated how future technological innovations might change the LCA impact of plaice and cod and imported salmon, tilapia and pangasius from aquaculture. Although we are not able to quantify the changes in environmental impact, the analysis demonstrates the following:

- Expected technological improvements offer possibilities for reducing the environmental impact of both wild-caught fishing and aquaculture.
- The current developments in both fishing technology and fisheries management will most probably result in a significant reduction of the environmental impact of wild-caught whitefish in the Netherlands in the coming years.
- All technologies that reduce fuel use have a direct positive impact on the LCA.
- Other changes, such as a shift to biofuels or changes in the diet of aquaculture, all come with pros and cons. There is no easy win.
- The consequences of changing feed sources for aquaculture on the LCA are dependent on the source of feed (plant vs fish).

5.2 Discussion

This desk study concerning the environmental impact of North Sea plaice and cod is the first of its kind. A systematic analysis of environmental impact, enabling comparison with other fish or meat, was not available. We have presented the conclusion of our comparison but we wish to formulate the following points of discussion.

Regarding the methodology used, it should be emphasised that:

- We tried to include sole in the LCA but no proper information was available.
- The LCA is merely part of a broader analysis of environmental impact. An integrated comparison of the environmental impact of plaice, cod, salmon,

tilapia and pangasius also requires insight into the impact on ecosystems. Currently, there is no suitable information available for including such impact in the LCA.

- Current estimates of the GWP of farmed salmon, tilapia and pangasius might be underestimated, because on-farm emissions of N_2O (greenhouse gas with a significant impact) are not included.
- Under current conditions, the life cycle assessment does not include the energy used while building the vessel. In LCA analyses, it is common practice to omit this impact, as it constitutes less than 10% of the total energy use. Reducing fuel consumption means that the relative weight of energy use during construction increases. This may mean that to obtain a methodologically sound LCA, energy should be included in the future as well.
- Given the limitations of a desk study, it was also impossible to collect more information on the acidification and eutrophication potential of pork and chicken.

Regarding the outcome, the following should be noted:

- This study shows that the environmental impact of wild-caught North Sea whitefish is comparable to that of imported fish from aquaculture. The study therefore does not directly offer new arguments for better positioning in the market.
- The fisheries sector is concerned with innovation, and innovation will reduce the environmental impact of fisheries in the short term. Fuel-saving technologies in particular will lead to reduced environmental impact in the near future.

We present the following suggestions for future action:

- To understand the best positioning for North Sea fish in general, it is first necessary to know how consumers look at these products and their production methods.
- Subsequently, the results of this study on the environmental impact of plaice and cod, and information on fisheries' efforts in terms of innovation, can be communicated to a selected group of consumers.

The results of communication should be monitored and evaluated. If this proves to be successful, a larger communication campaign can be developed to improve the position of wild-caught North Sea whitefish.

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